## Fast Automatic Arc Detection

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Searching For Strong Lenses in Large Imaging Surveys

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- Motivation
- Arcfinder method
  - Partitioning into cells
  - Cell transport
  - Cell ellipticities
  - Cell correlation and object generation
  - Graph generation
- Problems / future work
  - Problems: spurious detections
  - Future work
- 4 Results
  - HST / WFPC2



- depends on intensity scaling
  - → hidden faint arcs near bright objects possible
- ambiguous feature classification bad for statistics
- data volume increases rapidly with future surveys
- needs a priori information
  - → selection effects
  - → hides arcs near dark clusters

Fast, automated arc detection is desireable.



Partitioning into cells

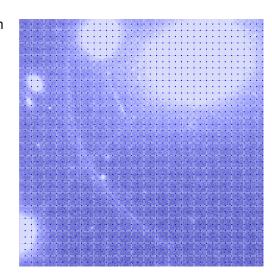
distribute cells on





Partitioning into cells

 distribute cells on rectangular grid

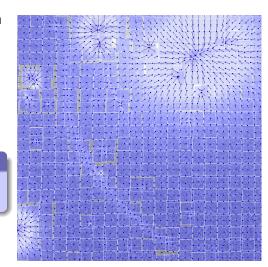




- distribute cells on rectangular grid
- shift to local centre-ofbrightness

## centre of brightness

$$\bar{\vec{X}} = \frac{\int_A \vec{x} q(I(\vec{x})) d^2 x}{\int_A q(I(\vec{x})) d^2 x}$$

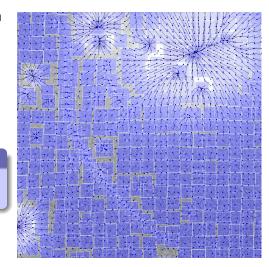




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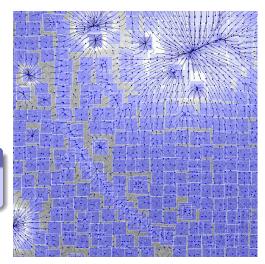


Outline

- distribute cells on rectangular grid
- shift to local centre-ofbrightness

## centre of brightness

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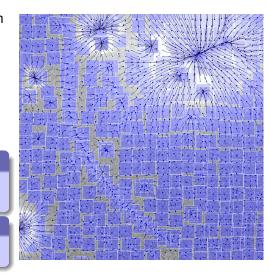
- distribute cells on rectangular grid
- shift to local centre-ofbrightness
- ellipticities

## second-moments Qii

$$\frac{\int_A (x_i - \bar{x}_i)(x_j - \bar{x}_j) q(I(\vec{x})) \,\mathrm{d}^2 x}{\int_A q(I(\vec{x})) \,\mathrm{d}^2 x}$$

## complex ellipticity $\chi$

$$\chi = \frac{Q_{11} - Q_{22} + 2iQ_{12}}{Q_{11} + Q_{22}}$$





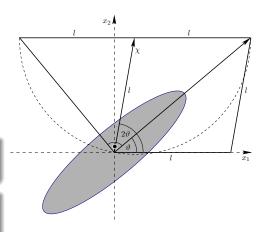
- distribute cells on rectangular grid
- shift to local centre-ofbrightness
- ellipticities ⇒ orientations

## complex ellipticity $\chi$

$$\chi = \frac{Q_{11} - Q_{22} + 2iQ_{12}}{Q_{11} + Q_{22}}$$

#### orientation

$$\chi = \frac{(1-r^2)}{(1+r^2)} \exp(2\mathrm{i}\vartheta)$$





Results

Outline

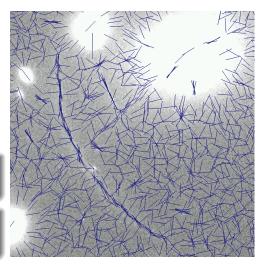
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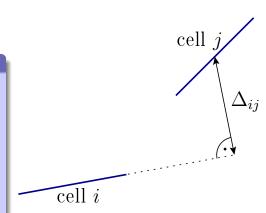
- cell correlations c<sup>i</sup>
- $c^i > c_{\text{thres}} \Rightarrow \text{add}$

# cell correlation

$$c^{i} = \frac{1}{|\mathcal{N}|} \sum_{j \in \mathcal{N}} c^{ij}$$
 $c^{ij} = c^{ij}_{d} c^{ij}_{x}$ 
 $c^{ij}_{d} = |\vec{e}^{i} \vec{e}^{j}|$ 
 $c^{ij}_{x} = \max \left(1 - \frac{\Delta_{ij}}{d}, 0\right)$ 

N : cell neighborhood  $\Delta_{ij} = \left| (\vec{x}^j - \vec{x}^i) \times \vec{e}^i_\perp \right|$ 

d: initial separation





Results

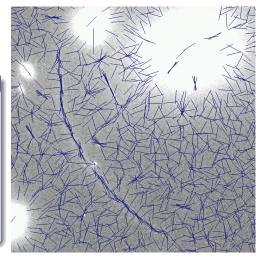
Outline

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N : cell neighborhood  $\Delta_{ij} = \left| (\vec{x}^j - \vec{x}^i) \times \vec{e}_{\perp}^i \right|$ d: initial separation





Cell correlation and object generation

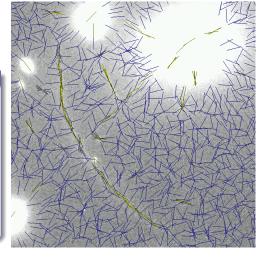
- cell correlations c<sup>i</sup>
- $c^i > c_{\text{thres}} \Rightarrow \text{add}$

## cell correlation

$$egin{aligned} c^i &= rac{1}{|\mathcal{N}|} \sum_{j \in \mathcal{N}} c^{ij} \ c^{ij} &= c^{ij}_d c^{ij}_x \ c^{ij}_d &= |ec{e}^i \ ec{e}^j| \ c^{ij}_x &= \max \left(1 - rac{\Delta_{ij}}{d}, 0
ight) \end{aligned}$$

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Results

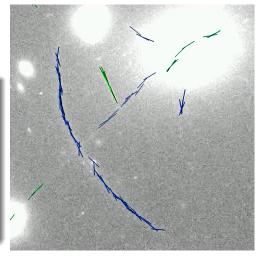
- cell correlations c<sup>i</sup>
- $c^i > c_{\text{thres}} \Rightarrow \text{add}$ cell i to an object

## cell correlation

$$c^{i} = \frac{1}{|\mathcal{N}|} \sum_{j \in \mathcal{N}} c^{ij}$$
 $c^{ij} = c^{ij}_{d} c^{ij}_{x}$ 
 $c^{ij}_{d} = |\vec{e}^{i} \vec{e}^{j}|$ 
 $c^{ij}_{x} = \max \left(1 - \frac{\Delta_{ij}}{d}, 0\right)$ 

 $\mathcal{N}$ : cell neighborhood  $\Delta_{ij} = \left| (\vec{x}^j - \vec{x}^i) \times \vec{e}_{\perp}^i \right|$ 

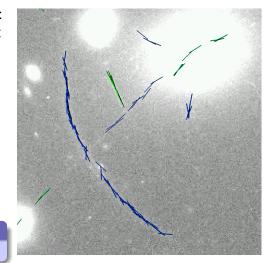
d: initial separation





Outline

- basic object filter: minimal cellcount and diameter
- generate linear



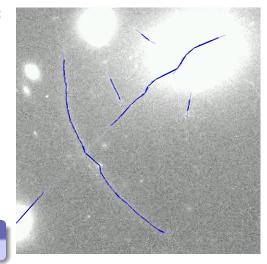
#### objects:

unsorted sets of cells



Outline

- basic object filter: minimal cellcount and diameter
- generate linear graphs following arc ridgeline



#### objects:

unsorted sets of cells

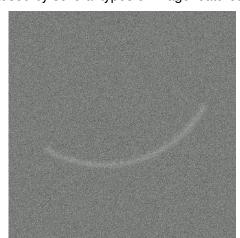


Problems: spurious detections

Spurious detections caused by several types of image features:

- Poissonian noise / pixel correlation

- point sources



Problems / future work

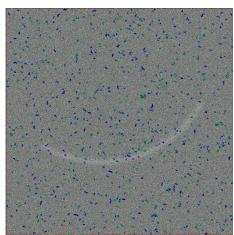


Problems: spurious detections

Outline

### Spurious detections caused by several types of image features:

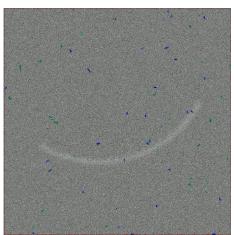
- Poissonian noise / pixel correlation scale size 5: 715 objects
- galaxies
- spikes and blooming
- point sources





#### Spurious detections caused by several types of image features:

- Poissonian noise / pixel correlation scale size 7: 49 objects
- galaxies
- spikes and blooming
- point sources





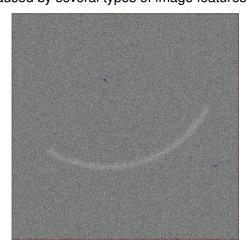
Results

Problems: spurious detections

Spurious detections caused by several types of image features:

- Poissonian noise / pixel correlation scale size 9: 2 objects

- point sources



Problems / future work



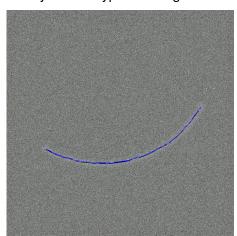
Problems: spurious detections

Outline

#### Spurious detections caused by several types of image features:

- Poissonian noise / pixel correlation scale size 39: 1 object

- point sources





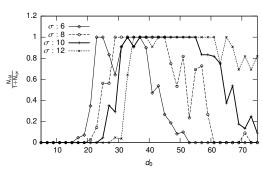
Results

Outline

### Spurious detections caused by several types of image features:

- Poissonian noise / pixel correlation scale  $\mapsto \frac{\text{detections}}{\text{candidates}}$ :

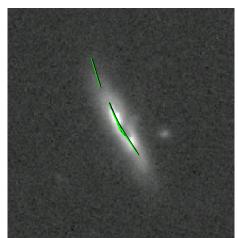
- point sources





#### Spurious detections caused by several types of image features:

- Poissonian noise / pixel correlation
- galaxies
- spikes and blooming
- point sources



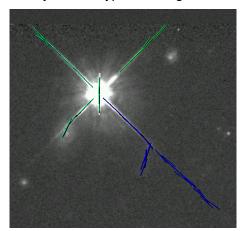


Results

Problems: spurious detections

#### Spurious detections caused by several types of image features:

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Results

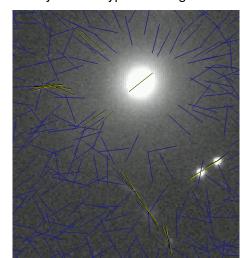
#### Spurious detections caused by several types of image features:

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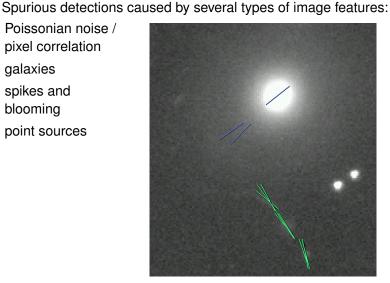


- Poissonian noise / pixel correlation
- galaxies
- spikes and blooming
- point sources





- Poissonian noise / pixel correlation
- galaxies
- spikes and blooming
- point sources





Future work

Outline

- post processing to remove as many spurious detections as possible
- determination of detection efficiency using simulated images
- application to datasets



Abell2390 by HST WFPC2

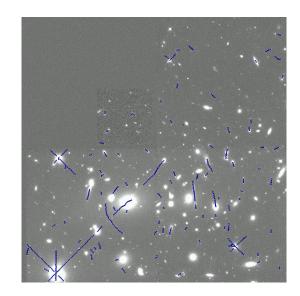
Processing time approx. 2.7s on 2.26GHz CPU





Abell2390 by HST WFPC2

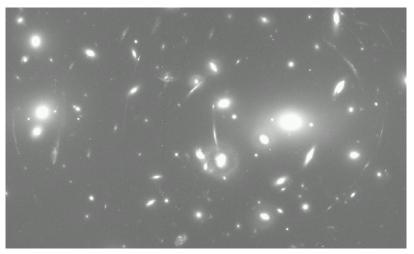
Processing time approx. 2.7s on 2.26GHz CPU





#### HST / WFPC2

Outline



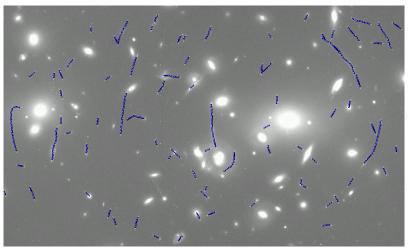
HST WFPC2 image of Abell2218 with several detected arcs. Also several false positives.



Results

#### HST / WFPC2

Outline



HST WFPC2 image of Abell2218 with several detected arcs. Also several false positives.



Results